

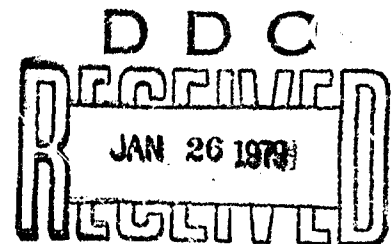
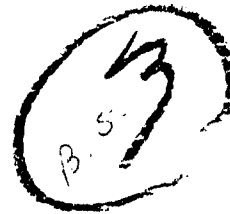
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THE RADOT CODE
FOR THE
TRACKING OF RADAR INCIDENT
ON TREES



Final Report

M. O. Cohen
H. A. Steinberg

February 1978

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20. Abstract (continued)

axis vector) and the depth.

Radot has been successfully installed on the ETL CDC-6400 computer.
Other versions, for IBM-360 or CDC-6600 computers are also available.

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ABSTRACT

A computer code, RADOT, has been developed to track incident radar through forests consisting of realistically simulated trees.

RADOT fires parallel radar rays at the simulated forest and records information for all materials intersected between the origin and the ground. This information includes type of object (branch, twig or leaf), its size and orientation parameters (components of normal or axis vector) and the depth.

RADOT has been successfully installed on the ETL CDC-6400 computer. Other versions, for IBM-360 or CDC-6600 computers are also available.

1. INTRODUCTION

The distinctive radar "signature" of a military object is a prime mechanism for its acquisition as a target. A major problem in target recognition is the radar background generated by a masking environment. This could be artificial, such as camouflage nets, or natural, such as vegetation. In order to cope with this problem, it is important to be able to quantify the expected background, so that target-background contrasting features might be identified, thus indicating the appropriate specifications for detection hardware.

Field measurements of radar return could be used for determining natural background. However, this can be quite expensive and time-consuming. Alternatively, one can use computer simulation, which can be much cheaper, recognizing that there is a possible problem of model accuracy.

This report describes the development of a simulation system to be used in the calculation of radar return from forests, where the micro-physics of radar scattering is left open, allowing improvements in accuracy as improvements are made in the physical model.

The framework of the system is a computer model of trees and forests^{1,2,3}, which Mathematical Applications Group, Inc. (MAGI) has adapted for use in the study of radar signatures. As described in the sections which follow, the code accepts as input, the type of tree(s) desired, (from a current library of four tree types) and the distribution of these trees within a forest area. From these data, and the angle the incident radar makes with the downward vertical direction, the code determines, as a function of height above ground, the angular distributions of hits with leaf and twig surfaces and the angular and size distributions of hits with woody branches and trunks. The essential use to which these results can be put in the future is to reduce the exceedingly complex geometry of a forested area to a set of distribution functions for each

of a number of horizontal single-reflection layers. Subsequently, these distributions will permit the determination of reflection and transmission matrices for each layer - each matrix representing scattering from a set of incident channels to a set of emergent channels. From these matrices, a reflection matrix for the entire system can be constructed.

The sections which follow describe the new code, RADOT (radar on trees), developed by MAGI to obtain the leaf, twig and branch distributions referred to above. (The second-stage matrix code was not within the scope of the current work.)

RADOT is currently operational on the IBM 360 and CDC 6400 and 6600 systems. The CDC 6400 version has been installed at the Engineer Topographic Laboratory (ETL).

2. SIMULATION OF A FORESTED AREA

2.1 Preliminary Generation of the Forest Configuration

Prior to the RADOT code firing and tracking simulated radar rays through a forested area (in order to obtain angular and size distributions), it must first have available, as input, a complete description of the forest of interest. This consists of two parts. The first part, described in Section 2.2, fixes the location of trees within the forest. In addition to its location, each tree must also be described by its tree type (e.g., pin oak, cottonwood) and by its size and orientation relative to a pre-determined prototype tree. The second part, discussed in Section 2.3, determines the description of each prototype tree.

2.2 Forest Generator

Program FORGEN, developed previously by MAGI⁴, utilizes user input and built-in distribution functions to place "tree boxes" throughout a forested area. A tree box is an imaginary rectangular parallelepiped (RPN), perpendicular to the ground, which just fits over a tree. The tree itself is one of the prototypes, (see Section 2.3), scaled and reorientated (in the horizontal plane) by the FORGEN code.

FORGEN, itself, is probably a great deal more flexible than required by RADOT users. The code can generate tree boxes within specified areas, along boundaries, or at specific isolated points. Only the area option is needed for RADOT. Also, FORGEN can construct a forest consisting of several distinct "patches", but for RADOT one patch should be sufficient. Nevertheless, the complete code, along with its description, has been delivered to ETL.

The output of FORGEN is a permanent file (or magnetic tape) containing, for each tree in the forested area, a description of its enveloping tree box. The tree box data are grouped first by forest patch (if more than one patch exists) and then by tree type (if more than one tree type exists). These organized data are referred to as the "forest library".

2.3 Tree Generator

The tree generator was developed previously by MAGI⁵ in order to represent, with a high degree of faithfulness, the woody structure and leaf distribution of a tree. Based upon user-input, the tree generator explicitly describes, via connected truncated right angle cones (TRCs) the trunk and the primary and secondary branches. The size, shape, location and orientation of each primary or secondary branch is included in the tree description.

The actual "construction" of a tree is based on three prototype structures: the primary branch, the segment of the primary branch and the secondary branch.

The main trunk of the tree is a stack of TRCs. Copies of the primary branch (see below) are hung on the main trunk, as directed by input. Copies of secondary branches (also, see below) are also permitted on the main stem.

The primary branch consists of stacked sections of primary branch segments. Each of these segments consists of a TRC on which copies of secondary branches are hung.

The prototype secondary branch consists of a TRC capped by twig and leaf structure. This structure is resident in the model (one structure per tree type) and can be modified in its three dimensions by different amounts.

Two different computer models for each tree are constructed by the tree generator; a high resolution model and a low resolution model. These differ only in the treatment of twigs and leaves. The high resolution model is used only for representation of close-up trees for MAGI's earlier code which generates actual pictures⁶. (This model is not used by RADOT.) In the high resolution model, the twig and leaf structure is completely deterministic. The low resolution model is used for representation of far-away trees for MAGI's earlier code and also for radar tracking in RADOT. In the low resolution model, the twig and leaf structure is replaced by homogeneous "clouds" of twigs and leaves, as described below.

The tree generator constructs the tree box about the tree as noted in Section 2.2, above. This box is then divided in a regular lattice of 15x15x25 cells; the division by "25" being in the vertical direction. The tree components are then sorted into the lattice cells. (Note: A long branch can span two or more such cells.) For the low resolution model, computer experiments are first performed with the high density model to obtain the proper twig and leaf cloud densities for each cell. These densities are then assigned to each cell. Note that in all subsequent ray tracing with the low resolution trees, twig and leaf "hits" are determined statistically, based upon the cloud densities of the lattice cells.

To date, MAGI has processed four prototype trees in both the high and low resolution versions*. These tree data have been forwarded to ETL. The processed trees include:

1. Virginia Pine
2. Pin Oak
3. Cottonwood
4. "Averaged" Ft. Belvoir deciduous (mostly Gum) tree, without leaves.

*The prototype trees can be scaled in height (and other dimensions) by proper input to the FORGEN code.

The collection of processed trees is referred to as the "tree library".

2.4 Organization of Forest and Tree Data

The forest and tree data must be made available to RADOT on logical unit IDB (see Section 4.3). The order is as follows (all in binary):

1. Forest library (output of FORGEN)
2. A single number flag = 78130
3. The tree library (output of the tree generator)
containing each prototype tree referred to by
the forest library.
4. A single number flag = 15626

The apparently peculiar nature of the two flags (second and fourth items) has logical meaning only for MAGI's earlier code but was carried over for convenience for RADOT.

It is currently up to the user of RADOT to organize the forest and tree data as outlined in this section.

3. OPERATION OF RADOT

3.1 Problem Specification

After the forest and tree data are organized, as outlined in Section 2.4, above, the user supplies some additional preliminary information to RADOT.

These include:

1. Title
2. Card punch and output tape options
3. Number of height regions in which data are to be recorded
4. The elevation above ground for these height regions
5. The number of angular bins (equally spaced in cosine from $+1.$ to $-1.$) in which angular distributions are to be accumulated.
6. The number of diameter bins (equally spaced from user-supplied maximum diameter to zero) in which branch distributions are to be accumulated.
7. The center and horizontal dimensions of the section of the forest to be examined and the angle that the incident radar makes with the downward vertical.
8. The nominal number of radar rays to be "fired" at the forest. This is somewhat altered by the code, as explained below.

3.2 Preprocessing by RADOT

RADOT will accept the specification data as supplied in Section 3.1 and will perform the following preprocessor operations:

1. Construct a focal (firing) plane above the forest section as shown in Figure 1. This plane will be oriented so that radar fired with negative Z and positive X direction components, passes perpendicularly through the focal plane.

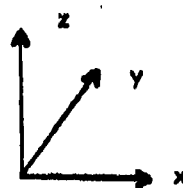
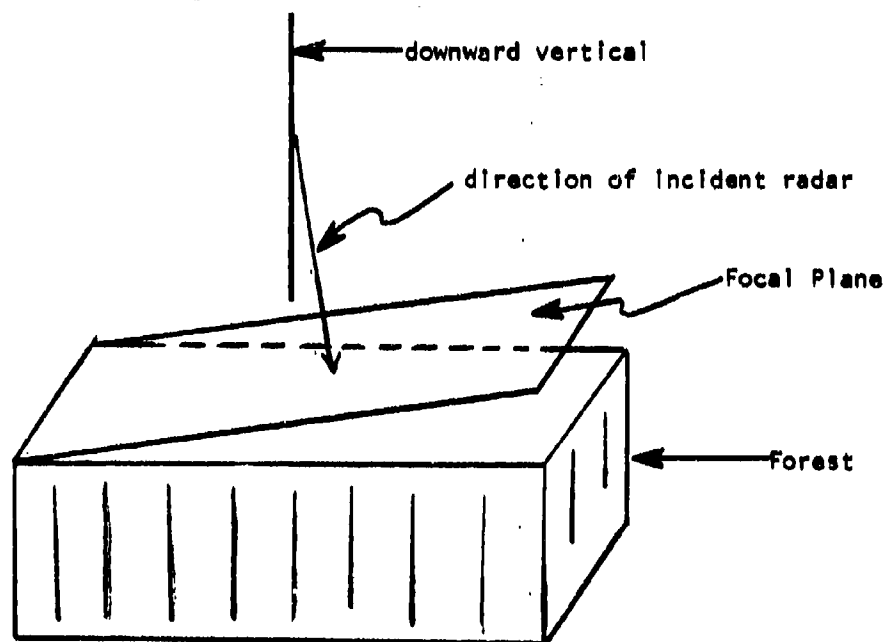


FIGURE 1 - Forest Area and Focal Plane

2. Consider an N^2 regular lattice of points on the plane, so that:

a. $N = 8J+1$

where J is an integer determined by condition "b"

b. $N \geq \sqrt{M}$ where M is the nominal number of rays specified by the user and N is as close to \sqrt{M} as possible while still satisfying condition "b"

The N^2 lattice points are uniformly located on the focal plane, and are so situated that radar rays passing through these points, will intercept the entire forest area (but no additional area) specified by the user, as described in Section 3.1.

3. RADOT will then divide the focal plane into smaller subsections (essentially rectangles of 8×8 points) and will determine, for each subsection, which of the tree boxes supplied by FORGEN could be intercepted by radar rays entering that subsection. This sorting information is saved and used subsequently by the ray firing routines as a computer running time saving device.

3.3 Ray Firing and Scoring

RADOT considers, one at a time, each grid point in the focal (firing) plane and "fires" a ray through that point at the user-specified angle with the downward vertical.

For each grid point, the code will consider, one at a time, each tree box selected as a possible intercept by the pre-sorting routines referred to in Section 3.2. The ray is tracked through the grid point (on the focal plane) towards a tree box. If it does intercept a given tree box further examination and possible scoring are required, as outlined in the following paragraph.

If it misses, the code examines the next possible tree box. This process then repeats until all the pre-sorted tree boxes are exhausted. At that time, the code proceeds to investigate the next grid point - a process which continues until all grid points have been examined. At that point, control is sent to the edit routine, as described in Section 3.4, below.

If a ray, fired through a particular grid point, does intercept a tree box, then further examination is required to determine if any branches or clouds of twigs or branches will intercept the ray. To accomplish this, the code considers the 15x15x25 internal cell array of the tree (see Section 2.3). The ray is tracked through those cells which it encounters along its path (inside the tree box) until it either hits the ground or exits laterally from the tree box.

For each cell traversed, the code determines if:

1. a branch is contained in the cell, and, if so, if the branch itself is actually hit.
2. the twig cloud density is greater than zero.
3. the leaf cloud density is greater than zero.

If material is encountered due to any one of the items listed above, (or for any combinations of such items), the following 8-word record is placed on an "Interaction file" (logical unit INT) for each of the encounters:

1. Type of encounter (i.e., branch, twig or leaf = 1, 2, or 3 respectively)
2. Score (=1 for branches; = statistical estimate for twigs or leaves - see below)
- 3-5. Directional Cosines (of major TRC axis for branches, of the perpendicular to the surface for twigs or leaves)
6. Height of Hit (=actual height for branches; =average height of cell box for twigs or leaves)
7. Diameter of Branch at Point of Encounter (applicable for branches only)
8. Ray Number (not currently used but available for future statistical analyses).

For twigs or leaves, the score (item 2) is of the form

$$1 - \exp(-\Sigma d)$$

where d is the distance of the ray through the cell and Σ is a macroscopic "cross-section" (i.e., probability of a "hit" per unit distance) which is directly related to the twig or leaf cloud density assigned to that cell.

After writing the 8-word record for each kind of encounter in the cell, the code proceeds to the next cell (if any) to continue the tracking process as if no hit had been made.

Upon the completion of all the rays, the interaction tape is rewound and sorted in the edit routine (Section 3.4).

3.4 Editing of Results

The edit routine rewinds the interaction tape (described in Section 3.3) and reads the data back, event-by-event. Each event is sorted according to its encounter type (i.e., branch, twig or leaf) and its height bin. A counter for the appropriate type-height bin is incremented by the event score (see Section 3.3). In addition, a similar increment is made in the appropriate type-height-angular bin - the angular bin currently being described only by the cosine of the angle between the upward vertical vector and the score direction cosines (i.e., the TRC axis for branches; the normal to the surface for twigs and leaves). The angular bin structure was specified by the user upon input. Finally, if the encounter was with a branch, an additional increment is made in the appropriate height-diameter bin - the diameter bin currently being described by the fraction of a maximum user-specified diameter.

Upon the completion of all sorting and incrementing, RADOT will then normalize all scores to a "per ray" basis and will further normalize all distributions so that their integrals are unity. All scores are then printed out and options are available to punch out these scores or to write them on output magnetic tape.

Finally, the edit routine will examine the total scores in each height bin and will determine and print out the subdivisions of each bin so that, assuming an originally uniform height distribution of scores within a given height bin, the probability of a hit in any given subdivision does not exceed a fixed probability, P_1 . Currently, (looking ahead to a single scattering matrix code), P_1 is set to 0.1. That is, the probability of two or more hits goes as $\sim 0.1^2$ or ~ 0.01 and so the chance of a multiple scatter within a subdivided height bin is very small.

4. CODE DESCRIPTION

4.1 Routines

The following paragraphs provide a brief description of each routine of the RADOT code.

MAIN (RADOT)

The MAIN program initializes some constants and reads input data describing the scoring regions, the distributions desired and the types of trees to be included.

It then calls CAMERA to locate the "firing position" and the focal (i.e., "firing") plane.

Subsequently, in a loop over the different types of trees, the following routines are called:

(1) FORRET - which extracts from the data base the portion(s) of the pre-calculated forest which lie in the specified investigation area.

(2) PREPAR - which, in order to speed up the ray-tracing in the latter stages of the code, examines the various rectangular areas on the focal plane, and records which specific trees can be hit by rays fired from the firing position through that rectangular area.

(3) MAMAGE - which controls the ray-tracing through the trees and the writing of interaction "hit" data on the interaction tape.

When all tree types have been analyzed, EDIT is called to edit the results.

CAMERA

Subroutine CAMERA reads in data describing the forest area to be investigated and the angle of the incident rays with the downward vertical. Based upon this information, CAMERA computes:

- (1) the firing position for all rays,
- (2) the location and inclination of the focal plane,
- (3) the first grid point (in the focal plane) to be examined, and
- (4) data which will subsequently allow subroutine VPICTU to determine all other grid points in the focal plane.

EDIT

Subroutine EDIT terminates and rewinds the interaction tape which is designated as logical unit "INT". EDIT will then read back each interaction event, one at a time, and first determine the height region of the event and the type of event (i.e., solid wood, twigs or leaves). The number of hits by height and type are incremented. The event data are then further evaluated to determine the proper polar cosine bin, (of the axis for solid wood, and of the normal vector for twigs and leaves), and the appropriate incrementing is performed. If the event is with the solid wood, the diameter of the wood is retrieved from the data and the appropriate incrementing is performed.

This procedure is continued until all interaction events have been retrieved, examined and sorted. At this point all results are printed out, including both absolute and normalized angular and diameter distribution data. Upon option, the results may also be punched out or written on an output file.

As a final step, EDIT will examine the accumulated data in each large (input) height region and will determine the layer boundaries, within each height region, so that the probability of a "hit", per incident ray, is no greater than P_1 . Note that P_1 is set by an executable statement in the MAIN code. It is currently set to 0.1 so that the chances of a multiple-hit goes as 10^{-2} which is a small enough probability.

FORRET

FORRET is called by the MAIN routine once for each type of tree specified by the user.

FORRET then performs the following operations, utilizing the forest data file on logical unit "IDB".

- (1) Verifies that the specified tree type exists on the tree library.
- (2) Examines each patch (sub-region) of the forest and determines whether that patch contains trees of the type currently under question. If it does, FORRET calls INROUT to determine whether the user-specified area to be examined lies in the patch. If it does not, the routine proceeds to the next patch. If it does, FORRET determines which trees (i.e., tree boxes) lie in the user-specified area, and writes the tree box information for those trees, on logical unit "IPD". Up to 5000 tree boxes (of a certain type of tree) may be found to exist within the user-specified area.

GGBOX

GGBOX is a routine to determine if a ray originating at a specified point and aimed at a specified direction will intersect a given (tree) box. If no, a logical variable "IMISS" is set to "TRUE". If yes, IMISS is set to "FALSE" and the distance to the box is determined.

GGTRC

GGTRC is similar to GGBOX, except that it is used for a truncated right cone (TRC).

INROUT

INROUT determines if any portion of the user-specified area to be examined lies within any portion of a given patch of the forest.

LRAYT2

LRAYT2 controls the tracking and scoring (if any) of a ray through a given tree box.

The tree box is divided into a 15x15x25 cell mesh - with the 25 subdivision being along the height vector. Each of these boxes, according to the tree type, may or may not contain solid wood, twigs, or leaves - or combinations of two or three of these components. The solid wood is explicitly located in space; whereas twigs and leaves, if they exist in a cell, are assumed to be uniformly distributed throughout the cell.

The ray will be tracked by LRAYT2 from the point where it enters the tree box to the point where it exits - either through a side or by striking the ground.

LRAYT2 calls LRIGID, which, in turn, tracks through the cells until one is found that is not empty. LRIGID will return to LRAYT2 the number of solid wood components in the current cell (if any) and the interaction cross section data for the homogenized twigs (if any) and the homogenized leaves (if any).

For each solid wood component, LRAYT2 will call GGTRC to determine whether an actual intercept was made. If so, the height of the hit (average height of the path through the TRC), the diameter, and the normalized direction cosines of the TRC axis will be recorded, along with other information, on the interaction tape ("INT").

For twigs and/or leaves a score of the type $[1 - \exp(-\Sigma d)]$, where Σ is the macroscopic cross section and d is the distance through the cell, will be computed for $\Sigma > 0$. The average height of the ray through the cell and the direction cosines of the normal to the twig or leaf will also be computed. These data, among others, will then be written on the interaction tape.

LRAYT2 saves considerable computer time, while tracking through the tree box, in the following manner. If, in the course of tracking through a specific cell, GGTRC determines that a certain piece of solid wood (TRC) is not intercepted by the ray, a flag is set so that the TRC will not be examined again (for that ray) for any other cell in which it may appear.

LRIGID

LRIGID tracks from cell to cell within a tree box. If LRIGID determines that one or more TRCs exist in a cell and/or homogenized twig or leaf material exists, it will return such information back to its calling routine, LRAYT2. The information about what is contained in a given cell is retrieved from the CELL and CELL2 arrays both of which were transferred to LRIGID via COMMON/TREE/. These data were originally set by the portion of the tree code (of the earlier work) which converts the tree from the high-resolution to the low-resolution model.

When LRIGID returns to LRAYT2, a logical variable "EXIT" is set. If the ray is still within the tree box, EXIT is set to "FALSE". If the ray has escaped from the tree box, EXIT is set to "TRUE".

MAMAGE

MAMAGE is called by MAIN, for each tree type, to control the tracking part of the code. MAMAGE reads in the tree data from logical unit "IPD" and calls VPICTU to begin the ray tracing.

PREPAR

PREPAR is called by MAIN, for each tree type. Its purpose is to pre-sort the tree boxes (in the user-selected part of the forest) so that only those tree boxes appropriate for a given rectangular area on the focal plane (i.e., only those tree boxes which can be intercepted by a ray from the firing point aimed through the given grid point) need be considered.

RANF

Function RANF is a random number generator. It selects a floating point number with uniform probability between 0. and 1.

REED

REED is an auxiliary routine called by PREPAR to read an array from a specified logical unit in the minimal amount of time.

VPICTU

VPICTU selects, one at a time, the grid points on the focal plane and starts all rays towards the trees at the user-specified angle to the vertical downward direction. It then calls VRAYTR to continue the tracking process.

VRAYTR

VRAYTR considers the focal plane grid point in question and retrieves, from logical units 3 and 10, the data for the appropriate tree boxes (i.e., those selected earlier by PREPAR). It then calls VRAYTI to continue the tracking process.

VRAYT1

VRAYT1 considers one at a time, the tree boxes (for a given focal plane grid point) as retrieved by VRAYTR. For each, VRAYT1 calls GGBOX to determine if the ray does actually intercept the tree box. If not, it proceeds to the next tree box. If it does, control is turned over to LRAYT2 for the actual tracking through the tree box. When all possible tree boxes have been examined, VRAYT1 returns control to VRAYTR.

WRIT

WRIT is an auxiliary routine called by PREPAR to write an array on a specified logical unit in the minimal amount of time.

4.2 Code Structure

Figure 2 displays the organization of the RADOT code and the labeled commons utilized by each routine.

4.3 Logical Unit Assignments

The card reader and printer are assigned units IN and OUT, respectively. The forest and tree data must be supplied from unit IDB and the interaction tape is unit INT. An important intermediate "scratch" file is unit IPD*. Currently, these units are assigned by executable statements in the MAIN routine as follows:

```
IDB=1
IN=5
OUT=6
INT=14
IPD=15
```

In addition, units 3, 10, 11, 12 and 13 are used as intermediate scratch files. Separate unit assignments can be made by the user for the optional punch and output files*.

*NOTE: If desired, file IPD can be rewound by the edit routine and used for tape (or disk) output. Tape 7 is usually used for punching cards, if that option is desired.

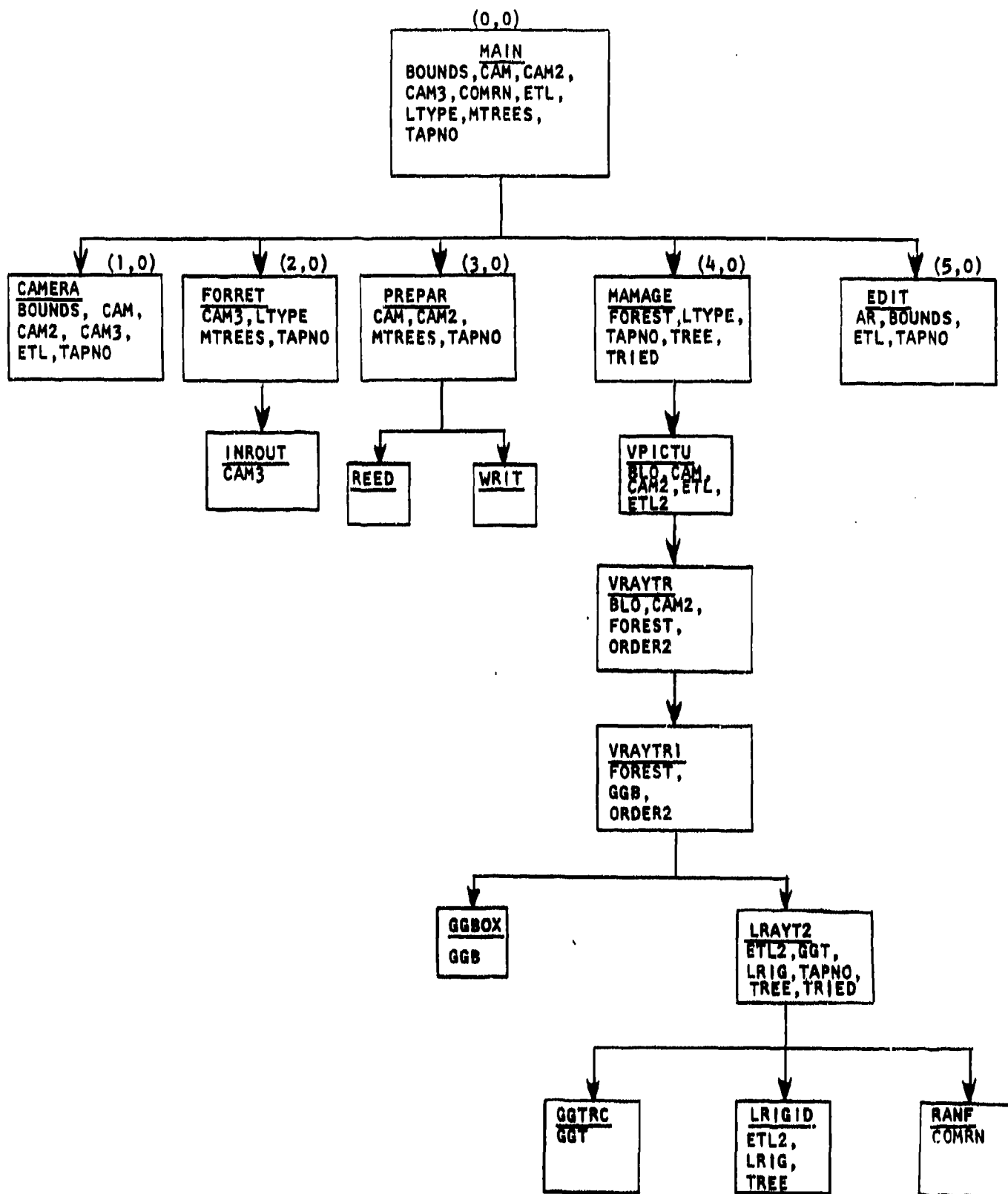


FIGURE 2 - Code Structure of RADOT, with labeled COMMONS

4.4 Error STOP Messages

Various error conditions will cause the RADOT code to terminate with numbered STOP statements. In such cases, the current routine, itself, provides information as to the cause of the STOP condition. As a user aid, the locations of the various STOP conditions are now provided:

<u>ROUTINE</u>	<u>STOP Number(s)</u>
MAIN (RADOT)	11
CAMERA	101, 102
EDIT	106, 107, 113
FORRET	20, 21, 22
LRAYT2	40, 42, 44
PREPAR	60

4.5 Input Description

The following is a complete description of the input required by RADOT:

1. TITLE (Format 20A4)

2. NMAC, IPUN, ITAP (Format 3I10)

NMAC = Number of height layers for which distributions shall be determined. (≤ 100)

IPUN = Punch option; =0 for no punch, = punch unit assignment for punch.

ITAP = Tape output option; =0 for no output tape, = tape unit assignment for output tape.

3. HITE (Format 6E12.4)

NMAC+1 boundary values (feet) of the layers.

HITE(1) must not be lower than the top of any tree.

HITE(NMAC+1) must be 0.

4. NTHET,NDIAM,DIAMAX (Format 2110,E12.4)

NTHET = number of equally spaced polar angle bins for distributions*

NDIAM = number of equally spaced diameter bins for distributions*

DIAMAX = maximum diameter of a tree (feet)

5. X0,Y0,XL,YL,COSTH (Format 5E12.4)

X0 = center of forest in X-direction (feet)

Y0 = center of forest in Y-direction (feet)

XL = X-length of forest (feet)

YL = Y-length of forest (feet)

COSTH = polar cosine of rays from vertical downward direction

6. IFR (Format 110)

IFR = specific forest patch to be examined**
= 0 neglect this option

7. MRAYS (Format 110)

MRAYS = nominal number of rays to be fired

8. JFIRST,JLAST (Format 2110)

JFIRST = tree no. for first tree***

JLAST = tree no. for last tree***

*NMAC*NTHET<2000; NMAC*NDIAM<2000

** If the forest contains more than one patch and consideration of only one patch is desired.

*** Use 1,2,3,4 for Virginia Pine, Pin Oak, Cottonwood, Ft. Belvoir-averaged Deciduous (without leaves), respectively.

4.6 Output Description

4.6.1 Organization of Output

The printed output consists of three parts:

1. Print-back of input
2. Intermediate results
3. Results of ray firing

These three parts are discussed in the sections which follow.

4.6.2 Print-Back of Input

RADOT prints back for the user the input as specified in Section 4.5, above. In addition to the nominal number of rays, the actual number of rays is printed out, as well (see Section 3.2).

4.6.3 Intermediate Results

Some of the intermediate results derived by RADOT prior to ray firing are printed out as extra information for the user. These include the following:

1. Firing Position - the nominal location of a firing position used to pre-sort the tree boxes.
2. Start of Focal Plane - the first point on the focal (firing) plane.
3. Increments - Δx , and Δy ; used in finding other points on the focal plane.
4. Forest Description - including for each patch in the forest, (there may be more than one):
 - a. patch number
 - b. user-selected patch (if any)
 - c. number of trees by tree type.

Under item 'c', the tree type is a two digit number, where the first digit is the tree type and the second digit is 1 or 2, depending upon whether the forest was described by the high or low resolution model, respectively. Although RADOT uses the low resolution tree model only, it can pick up and utilize a forest description (from FORGEN) with the high resolution tree box since the tree boxes for both resolution models are identical.

5. Number of Trees before Sorting - the number of trees selected as potentially being hit by rays fired through the selected points on the focal plane.
6. Tree Sorting - the sorted and selected tree data are stored on scratch files 11, 12 and 13. This edit indicates how many trees are on each file. Since a tree can be entered on more than one file, the sum of the trees listed here can exceed the number given in item 5.
7. Tree Assignments (repeated for files 11, 12 and 13) - the number of trees for each focal plane area assigned to this file is given, as well as the tree numbers in the table which follows as item 8.
8. Tree Origins (repeated for files 11, 12 and 13) - the tree number and the tree box x and y origin for each tree assigned to this file.
9. Number of Trees after Sorting - some trees originally selected in item 5 may have been eliminated from further consideration. Hence item 9 is not necessarily identical to item 5.
10. Forest Complete through Tree Type - printed out for each completed tree type.

4.6.4 Results of Ray Firing

The final edit is printed out for the user, as described in Section 3.4. Punched out results and results on an output disk file (or magnetic tape) are available as well as options.

The sample problem shown in Section 5, illustrates the format of the output.

5. TEST PROBLEM

5.1 Description of Problem

The demonstration problem, described in this section, consists of rays fired at a patch of a forest previously generated at MAGI by the FORGEN code.

This patch, (number 1 of the entire forest), consists of tree types 1 and 2 in the tree library, which are the Virginia Pine and the Pin Oak, respectively. As in all runs with RADOT, the low-resolution tree models are used.

The trees are randomly mixed in the forest with the pine tree boxes and oak tree boxes covering 50% and 40% of the forest surface, respectively. The pine trees are 5.0 ± 0.5 feet in height while the oak trees are 12.0 ± 0.2 feet

The number of rays that are tracked is 1089 (in a 33×33 grid). They are fired at a segment of the selected forest patch which extends in the "x-direction" from 360 to 420 feet and in the "y-direction" from 700 to 760 feet. There are 86 pine trees and 57 oak trees in this rectangular segment. The rays intercept the forest at an angle of 25.842° (i.e., cosine of 0.900) with the downward vertical.

Scores are accumulated in 3 altitude bins with height boundaries of 12.3, 8.2, 7.2 and 0.0 feet.

Six polar bins are used for the cosine distributions of the normal vectors to the surfaces of the twigs and leaves and for major axes of the woody segments. Five diameter bins are used for the woody segments.

The problem ran for 84 seconds on an IBM 360/65 computer.

5.2 Input

The page which follows displays the input to the test problem.

	TREES NOS. 1 AND 2	PATCH NO. 1
3	0	0
8.2	7.2	0.
6	5.3.0	
730.	L.C.	D.9
2.000		
1	2	

FIGURE 3 - Input to Test Problem

5.3 Results of Ray Firing

The pages which follow display the output edit. (This format may be altered by ETL in the future.)

Note that for the distributions, the first set of data are the absolute results (hits/ray) and the second set of data are the results normalized to unity.

Also note that the total number of hits between heights of 7.2 feet and 0.0 feet is 0.2879 per ray. Since this exceeds the maximum allowed value of 0.1, RADOT breaks this range into intermediate ranges with the intermediate boundaries being printed out. For the other two height layers the number of hits per ray are less than 0.1 and so no further subdivision is required.

FDIT

INPUT LAYER NO. 1 HEIGHT RANGE FROM 12.50 TO 8.20 FEET

SOLID LOG 0.0

THEIA. 1 TO -1 0.0 0.0 0.0 0.0 0.0

DIAMETER. 10-10-HI 0.0 0.0 0.0 0.0 0.0

TWIGS 0.0016

THEIA. 1 TO -1 0.0005 0.0005 0.0003 0.0002 0.0
0.3350 0.3369 0.2036 0.1073 0.0171 0.0

IFAVES 0.0581

THEIA. 1 TO -1 0.0190 0.0221 0.0100 0.0001 0.0
0.3270 0.3803 0.1711 0.1048 0.0171 0.0

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FIGURE 4 - Output of Test Problem

(page 1 of 4)

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INPUT LAYER NO. 2	HEIGHT RANGE FROM	8.20 TO	7.20 FEET	
SOLID WOOD	0.0018			
THEIA. 1 TO -1	0.0 0.0	0.0 0.0	0.0018 1.0000	0.0 0.0
DIAMETER. 10-10-MI	0.0018 1.0000	0.0 0.0	0.0 0.0	0.0 0.0
TWIGS	0.0012			
THEIA. 1 TO -1	0.0005 0.4725	0.0004 0.3097	0.0007 0.1442	0.0 0.0
LEAVES	0.0286			
THEIA. 1 TO -1	0.0068 0.3067	0.0115 0.4002	0.0051 0.1763	0.0 0.0

FIGURE 4 - Output of Test Problem

(page 2 of 4)

INPUT LAYER NO. 3	HEIGHT RANGE FROM	7-20 TO	0.0	FFT
SIN ID WOOD	0.0395			
THETA. 1 TO -1	0.0147 0.3721	0.0110 0.2791	0.0064 0.1628	0.0046 0.1164
DIAMETER. 10-10-HI	0.0285 0.7209	0.0083 0.2093	0.0028 0.0698	0.0 0.0
TWIGS	0.0102			
THETA. 1 TO -1	0.0045 0.4379	0.0030 0.2968	0.0017 0.1666	0.0009 0.0873
LEAVES	0.2382			
THETA. 1 TO -1	0.0755 0.3168	0.0924 0.3679	0.0428 0.1797	0.0234 0.0981
				0.0042 0.0177
				0.0 0.0

FIGURE 4 - Output of Test Problem

(page 3 of 4)

#IGHT BOUNDS FOR SCATTER PROBABILITY OF 0.10				
LAYER NO.	1	MAX. HEIGHT IS	12.30	MIN. HEIGHT IS 8.20 FFFI
LAYER NO.	2	MAX. HEIGHT IS	8.20	MIN. HEIGHT IS 7.20 FFFI
LAYER NO.	3	MAX. HEIGHT IS	7.20	MIN. HEIGHT IS 0.0 FFFI
INTERMEDIATE LAYERS				
	4.80	2.40		

FIGURE 4 - Output of Test Problem
(page 4 of 4)

6. REFERENCES

1. J. Brooks, et al., "An Extension of the Combinatorial Geometry Technique for Modeling Vegetation and Terrain Features", BRL Contract Report No. 159 (June 1974).
2. J. Brooks, H. Lichtenstein and H. Steinberg, "Computer Simulation of Terrestrial Scenes", MAGI-P-7096 (Jan. 1975).
3. J. Brooks, R. Goldstein and H. Steinberg, "A Computer Simulation System for the Production of Realistic Photographs of Terrestrial Scenes", MAGI-P-7126 (July 1976).
4. Ibid., pp. 15-26.
5. J. Brooks, et al., op. cit.
6. J. Brooks, R. Goldstein, and H. Steinberg, op. cit.